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Ecological knowledge and value of traded species: Local awareness of native turtles in Hainan, China

H. Ma[1,2], S. K. Papworth[1], T. Ge[3], X. Wu[3], C. Yu[3], H. Zhang[3], F. Xiao[4], D. Gaillard[5], J. Bielby[6] & S. T. Turvey[2]

1 Department of Biological Sciences, Royal Holloway University of London, Egham, UK
2 Institute of Zoology, Zoological Society of London, London, UK
3 College of Forestry, Hainan University, Haikou, China
4 Ministry of Education Key Laboratory for Ecology of Tropical Islands, Key Laboratory of Tropical Animal and Plant Ecology of Hainan Province, College of Life Sciences, Hainan Normal University, Haikou, China
5 Department of Natural Sciences, Dalton State College, Dalton, GA, USA
6 School of Biological and Environmental Sciences, Liverpool John Moores University, Liverpool, UK

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Correspondence
Heidi Ma, Institute of Zoology, Zoological Society of London, Regent's Park, London NWI4RY, UK. Tel: (+44) 07479903590; Email: heidi.ma@ioz.ac.uk

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Abstract

Wildlife trade is driving species extinctions globally, and the Asian Turtle Crisis is posing a threat in China as turtle species are collected from the wild and sold at high prices. Local ecological knowledge is increasingly used to determine the status of threatened taxa, but there is little understanding of wider relationships between indices of ecological knowledge and other conservation-relevant factors such as market values of traded species. To assess whether local people's awareness of potentially traded turtles might indicate direct interaction with trade in these species, we conducted 185 interviews in rural villages around Bawangling National Nature Reserve, Hainan, China. Interviewees were asked to free-list native turtles to determine species salience and then were shown photographs of the species to assess recognition and knowledge. We investigated relationships between species' salience, whether species were recognized, named and/or perceived to be traded by more people, and independently obtained market prices. Indices of species awareness varied among interviewees, but all species were reported to be traded by at least some people. There was no correlation between indices of awareness and market value, indicating that more valuable species were no more likely to be well known. However, the perception that turtles are traded irrespective of species is a concern for conservation because all species are then vulnerable to exploitation. Our results highlight that local communities should not be assumed to have accurate knowledge of traded species, with implications for the management of wildlife trade and conservation at the community level.

Introduction

Wildlife trade, both legal and illegal, affects species across the tree of life, fuels a global multibillion-dollar market and is a major cause of biodiversity loss (Bennett *et al.,* 2002; Scheffers *et al.,* 2020). The motivations underpinning wildlife trade are highly diverse, ranging from subsistence-based consumption to profiting from highly lucrative enterprises involving organized crime (Esmail *et al.,* 2020). Sustainable use of wildlife can constitute an important part of livelihoods and development for people (Booth *et al.,* 2021), but in the context of modern market economies, many conditions must be met for trade to be well-managed and ensured to be sustainable for wildlife populations, such as reliable licensing of farmed animals to distinguish from wild-caught ones (Xiao *et al.*, 2021b). In contrast, unsustainable hunting for consumption and trade has resulted in widespread defaunation, especially in biodiverse tropical regions (Benítez-López *et al.,* 2017). Trade is influenced by various factors, including awareness, knowledge, subsistence and financial needs, and the perceived values and cultural significance of wildlife species. For example, the pursuit of social status may motivate a consumer to prefer wild-caught animals over farmed ones, while a supplier may have more incentives to trade wildlife if there are economic benefits and connections to markets (Cooney *et al.,* 2017; Veríssimo, 't Sas-Rolfes, & Glikman, 2020; Turvey *et al.,* 2021). However, current evidence on these relationships is often insufficient for effective mitigation (Challender, Harrop, & MacMillan, 2015). Monitoring the market is key to understanding what species are traded, where, how much and by whom. However, gaps remain in developing robust ways to monitor the extent of trade, especially of lesser-known species ('t Sas-Rolfes *et al.,* 2019). This is a particular concern in regions that have limited capacity in the interdisciplinary research needed to generate evidence on wildlife trade at the local community level (Wang *et al*., 2021b; Ma *et al.,* 2022).

Both legal and illegal wildlife trade is difficult to quantify and is limited by the ability of researchers to gather data systematically, and some conventional market and consumer survey approaches are inadequate because of the clandestine nature of trade activities and networks (Wong, 2019). The supply chain of wildlife trade often originates among local communities living near natural habitats of exploited species, and efforts to mitigate the impacts of trade are increasingly focused on reducing hunting pressure at the community level (Biggs *et al.,* 2017; Cooney *et al.,* 2017). To achieve this goal, more active involvement of local communities is required to understand human–wildlife interactions and reduce hunting pressure (Roe & Booker, 2019).

A key stage in this process is to explore how local understanding of trade might be reflected in local ecological knowledge, or the understanding of one's environment based on lived experience (Pham *et al.,* 2020). This body of knowledge is increasingly used as evidence in conservation (Berkes, Colding, & Folke, 2000; Newing, 2011). Of particular relevance to understanding wildlife trade is the fact that environmental perceptions (the understanding or conception of factors associated with the environment) and natural resource management are known to be interrelated and influence each other (Bennett, 2016). Such perceptions include environmental awareness, such as knowledge of locally occurring species or environmental change. Awareness can be demonstrated by people's ability to recognize particular species; this familiarity is indicative of having encountered the species and can be used as a tangible metric for evaluating local ecological knowledge (Turvey *et al.,* 2010; Qian *et al.,* 2022). However, perceptions can be influenced by people's experience, knowledge, values and other personal characteristics and social and cultural norms (Bennett, 2016), and there has been little research to assess potential relationships between environmental perceptions and characteristics of wildlife trade. For example, comparing knowledge of high-value traded species with that of lower-value species could offer important insights for conservation; in the absence of other information on interactions between local people and wildlife, if there is a relationship between awareness of a species and the level of trade, assessing awareness could thus provide indirect information to gauge local trade levels in targeted species (Wang, Leader-Williams, & Turvey, 2021b). Awareness is known to be related to trade in some contexts; for example, species featured in popular culture become better known by consumers, which can drive market demand (Nijman & Nekaris, 2017). However, the relationship between awareness and market value can also be confounded by other intrinsic and extrinsic factors (e.g. socio-demographic, ecological and geographic), and there is currently no evidence for a positive relationship between awareness and market value of traded species.

Reptiles are severely threatened by human activity but are less studied than mammals and birds (Bland & Böhm, 2016). China has a high native turtle diversity that is heavily exploited (Gong *et al.,* 2017), and turtles and turtle products have traditionally been used for food, medicine, decoration and pets (Cheung & Dudgeon, 2006). This demand has led to widespread trade of both wild-caught and captive-bred turtles, driving wild turtle populations in China to the brink of extinction while also affecting species trafficked from elsewhere (Shi *et al.,* 2013; Wu *et al.,* 2020). However, baseline evidence on awareness and knowledge of turtle species among suppliers and consumers in China, and the relative monetary values of these species, remains difficult to obtain (Shi *et al.,* 2013; Gaillard *et al.,* 2017). In southern China, recent research at the local community level has revealed high variation in peoples' awareness of turtles, collecting behaviors and market prices (Wan *et al.,* 2015; Gaillard *et al.,* 2017), highlighting the need for more comprehensive research on how local ecological knowledge can inform conservation. Specifically, little is known about local knowledge and awareness of turtle trade, especially near and inside nature reserves (Gong *et al.,* 2017), and how it relates to the values of species in trade (Sung & Fong, 2018; Ye *et al.,* 2020).

In this study, we evaluated whether species with higher market values are better known to local people living near Bawangling National Nature Reserve (BNNR) in Hainan Province, China, by investigating the relationship between various indices of local awareness of different turtle species and comparing these baselines with relative market values obtained independently by researchers familiar with the trade. We quantitatively assessed which of the ten native Hainanese freshwater turtle species are most salient, most identified from photographs, most named by their common Chinese name and most reported to be traded locally, and then explored how knowledge and perceptions of trade vary among local respondents. Our analyses controlled for demographic, sociocultural and behavioral characteristics, such as age, gender and education that are known to affect ecological knowledge within rural communities in China and elsewhere (Pilgrim *et al.,* 2008; Reyes-García *et al.,* 2010; Turvey *et al.,* 2010; Kai *et al.,* 2014). By identifying patterns in local perceptions of traded species, our results evaluate the possibility of using ecological knowledge as a proxy for monitoring their perceived value and potential impact from exploitation, to provide new insights for improving the conservation of Hainan's turtle fauna. These findings also contribute more widely to tackling unsustainable wildlife trade by demonstrating the value of incorporating local perceptions and ecological knowledge into conservation baselines for data-poor taxa and regions.

Materials and methods

Study site

Interviews were conducted in low-income rural villages close to BNNR (18°57–19°11 N, 109°03–109°17 E), a 300 km^2 protected area established in 1980 (Fig. 1). Extensive field surveys for the big-headed turtle (*Platysternon megacephalum*) have

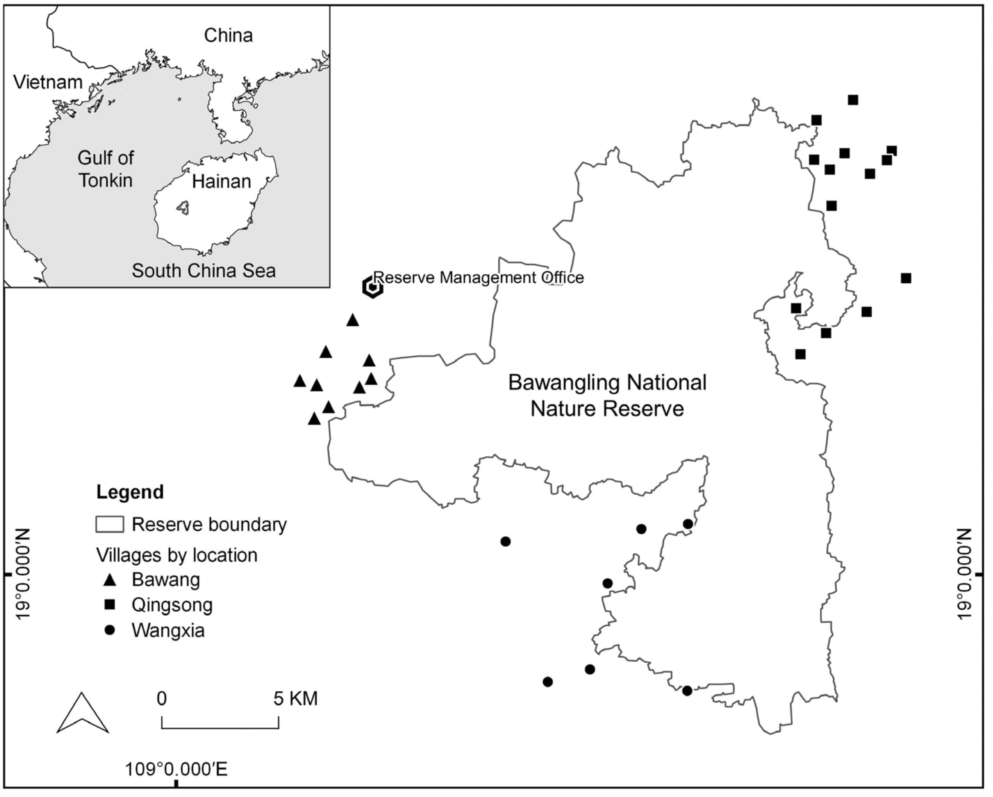

Figure 1 Villages visited in this survey adjacent to BNNR in western Hainan, China. Villages located in three areas are distinguished by different symbols.

been conducted in recent years in BNNR and other nature reserves in Hainan (Xiao *et al*., 2021a), but surveys of other turtle species are limited (Gaillard *et al.,* 2017). Hunting and trapping of wildlife continue in Hainan's forests, including inside nature reserves (Gong *et al.,* 2017; Xu *et al.,* 2017; Wang, Parham, & Shi, 2021a). Local people are mainly of Li ethnicity, with some Miao and Han people also residing in the area, and rely primarily on agriculture for their livelihoods (Davies & Wismer, 2013). Villages tightly surround the reserve (Fig. 1).

Data collection

Data were collected between 27 February and 1 April 2019 by HM, TG, XW, CY and HZ. All 30 villages within 3 km of the boundary of BNNR were surveyed. Villages naturally cluster in three areas (Bawang/Qicha town, Qingsong and Wangxia), with clusters sharing village-level government, road access, bus routes and stops and small shops (Fig. 1). These villages belonged to two counties (Changjiang and Baisha Li Autonomous Counties), which have a combined total population of c.397,000 people (Hainan Provincial Bureau of Statistics, 2021). Villages ranged between 15–150 households and 0.01–0.17 km^2 in size (Qian *et al.,* 2022). The research team did not have previous relationships with these communities, and local wildlife or hunting experts were not specifically sought out. Individual household interviews were conducted by walking through each village and asking people door-to-door. A target of ten interviews (Guest, Bunce, & Johnson, 2006) was set for each village but was only achieved in three villages. Interviewees were informed about the study aims, that data were collected anonymously, that they could terminate or withdraw from the interview at any time for any reason, and could choose to not answer any question. Interviewees participated voluntarily and gave their free, prior and informed consent verbally due to low levels of literacy. A standard questionnaire that took 30–60 minutes to complete was used in all interviews, which were conducted in Standard Mandarin, the language understood and spoken by most adults in the region except very elderly people (Supplementary Material). The research was approved by Royal Holloway University of London's Research Ethics Committee (ID 535).

Information was first collected on interviewees' demographic characteristics, including gender, age, number of years lived in the village, ethnicity, highest education level and frequency of visits per month to the forest and nearest county-level town. Interviewees were then asked to free-list the common names of any turtles they knew were found around BNNR (cf. Newing, 2011). Turtle names were recorded in the order of listing. Finally, for a set of 11 turtle species, interviewees were shown two photos of each species and asked whether they recognized the species if they knew its name, the last place and time they saw it and if they thought the species was traded. These questions were first asked as closed-ended questions that elicited a 'yes'/'no'/'do not know' response, and were followed up with open-ended questions that allowed interviewees to provide any additional information they wanted. Recognition and naming are treated as two separate metrics because it is possible for someone to recognize a species but not know its name and vice versa (Turvey *et al.,* 2019). The set of species included all ten native Hainanese freshwater turtles, and a negative control species only found in eastern North America (spotted turtle *Clemmys guttata*), to screen for interviewees whose answers may be unreliable. Species were shown in the same random order for all interviews, and species names were not provided to interviewees (Table S1).

Information on the market price of each species was not asked during interviews to reduce the risk of stimulating poaching that might result from prompting interviewees to think about the potential economic value of wild turtles. Price information was only recorded when voluntarily given by interviewees in open-ended questions and during discussions. When more than one interviewee provided a price for a species, the mean price and range were calculated. Instead, recent (2019) estimated local market prices of native turtles were determined from independent data gathered by DG and FX through contacts at turtle captive breeding facilities, online trade networks and market surveys in Hainan (Gaillard *et al.,* 2017), and from additional available information in published literature (Wang *et al.,* 2005; Gong *et al.,* 2006; Sung & Fong, 2018), because turtles harvested from the communities in this study are sold both locally and more widely in southern China.

Data analysis

Various local names exist for native Hainanese turtle species; ambiguity in determining species identifications from local names was reduced using identification criteria provided in Shi *et al*. (2013) and information previously provided to DG and FX during extensive previous interviews with local people and traders across Hainan (Table S1). Interviewees who claimed they knew the negative control species were excluded from all analyses ($n = 10$). Names that were ambiguous or did not refer to a specific species (e.g. 'turtle', 'small turtle', 'cheap turtle', 'river turtle', 'tree turtle', 'small headed turtle'; $n = 15$) were further excluded from analyses. One mention each of sea turtle (not found within BNNR) and common snapping turtle (*Chelydra serpentina*; locally present but not native to Hainan) were also excluded.

Statistical analyses were performed in R version 3.5.2 (R Core Team, 2018). The salience of the ten native turtle species was derived from free-listed names by calculating Smith's Scores in the R package AnthroTools (Purzycki & Jamieson-Lane, 2017). To quantify and compare which species was the most frequently free-listed, recognized from photographs, named, and reported to be traded, the proportions of responses for each attribute were calculated separately because different numbers of people answered each question. Proportions of interviewees who named each species and reported it was traded were calculated using the subset who recognized it from photographs. Species' relative trade values were ranked by estimated prices of wild-caught rather than captive-bred individuals.

Spearman's rank correlation tests were performed on all combinations between ranks of species salience and ranks of proportions of interviewees recognizing species, naming species and thinking they were traded, and prices provided separately by interviewees and by researchers. A further Spearman's rank correlation test was used to determine the relationship between ranks of species salience and proportions of sightings. Bonferroni correction was applied to adjust the significance threshold for p-values due to multiple testing.

Negative binomial generalized linear models (GLMs) with Poisson error distributions, used to model count data in integers with minimum values of 0, were used to determine which sociodemographic variables were associated with the number of turtle species that interviewees were able to recognize, name and thought were traded. The total number of species in each category were summed and analyzed as integers between 1 and 10; only interviewees who knew at least one species were included. A full model approach was taken because demographic variables were selected based on their potential impacts on the response variable as identified in the literature, to avoid favoring significant results and Type I errors (Kerr, 1998; Forstmeier & Schielzeth, 2011). Model predictors included: (1) age, (2) gender, (3) village area, (4) highest education level, (5) whether the interviewee went into the forest at least once a month (yes/no), (6) whether the interviewee went to the nearest county town at least once a month (yes/no) and (7) distance to county town (continuous variable measured in kilometers of road distance on Google Maps). An additional binomial GLM was also used to investigate whether recognizing and naming more species predicts whether interviewees could provide price data for at least one species (yes/no); education level and village location were excluded as predictors in this model due to low variation resulting in fitted probabilities of 0 or 1. Only interviewees of Li ethnicity were included in all analyses to control for ethnicity because there was limited variation in this interviewee characteristic (92.4% of interviewees were Li).

Results

Species salience, awareness and perceptions of trade

A total of 185 people were interviewed (Table S2). More than two-thirds were male (130). More people were interviewed in villages in Qingsong (124) than in Bawang (34) or Wangxia (27), where fewer people were encountered or were willing to participate. More than half of all interviewees (96) had either no formal education or were only educated to primary-school level. More than two-thirds (137) reported going to the forest at least once a month, but less than one-third (56) reported visiting the nearest county town at least once a month.

Responses about native turtles varied between species and by type of awareness and knowledge. In total, 57.7% (101/175) free-listed at least one species. The species mentioned most frequently were golden coin turtle (*Cuora trifasciata*), big-headed turtle and keeled box turtle (*Cuora mouhotii*), although no species was mentioned by more than half of all interviewees. Salience varied between species: the golden coin turtle was the most salient, followed by big-headed turtle and four-eyed turtle (*Sacalia quadriocellata*) (Fig. 2).

When shown turtle photographs, five species (Indochinese box turtle *Cuora galbinifrons*, Asian yellow pond turtle *Mauremys mutica*, wattle-necked softshell turtle *Palea steindachneri*, black-breasted leaf turtle *Geoemyda spengleri* and Chinese golden-thread turtle *Mauremys sinensis*) were not named correctly by anyone, yet were all perceived to be traded. Among the interviewees who recognized at least one turtle, the three most frequently correctly named species by proportion were big-headed turtle (75), Chinese softshell turtle (*Pelodiscus sinensis*) (69) and golden coin turtle (54), while the Chinese golden-thread turtle (*M. sinensis*) was recognized by the fewest interviewees (19).

Across the sample, 78.9% (138/175) of interviewees recognized at least one species, but no species was recognized by more than half of all interviewees (Fig. 3). Most interviewees recognized fewer than five species (79%, 139/175), and nearly half could not name any (43%, 75/175). There was further variation across proportions of interviewees who incorrectly named species or did not know their names; the wattle-necked softshell was the most incorrectly named and unnamed species, whereas no one named the golden coin turtle incorrectly and few did not know its name (Fig. 4). Frequency distributions of the number of species that interviewees recognized and correctly named are provided in Fig. S1. In total, 53.1% of interviewees (93/175) reported at least one species to be traded.

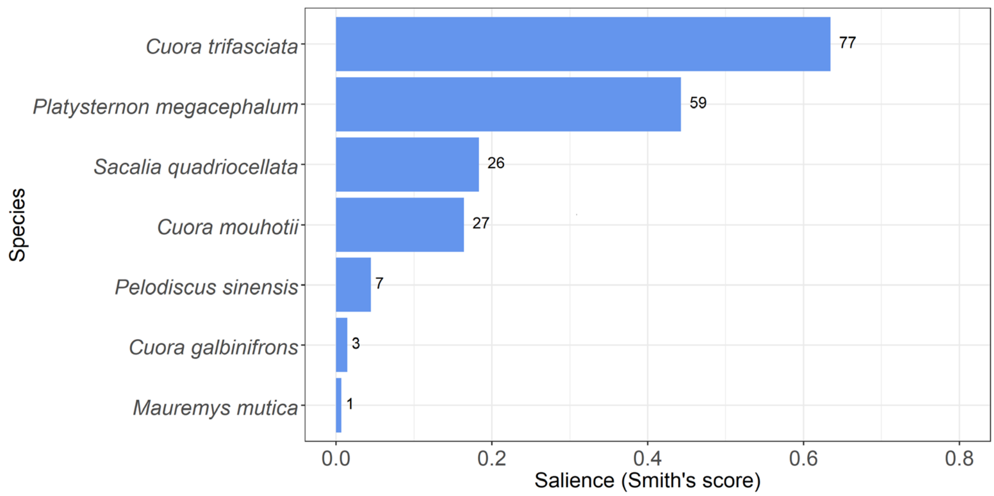

Figure 2 Smith's Score of salience for native Hainanese turtles calculated from free-listing order and frequency for 101 interviewees. Numbers on the bars denote the number of interviewees who mentioned each species.

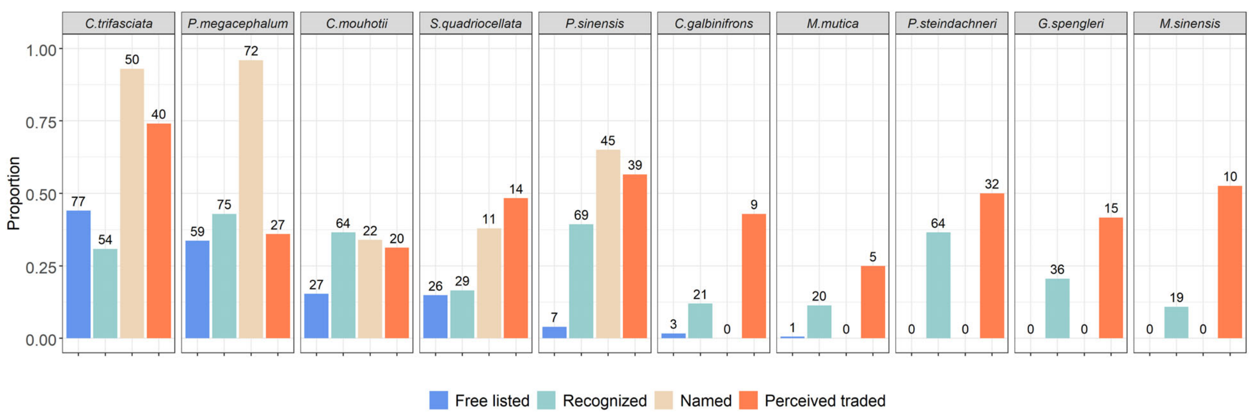

Figure 3 Interviewees' responses about ten native Hainanese turtle species when shown photographs of each species individually (n = 175). Proportions of interviewees who recognized species are calculated from the entire sample, and proportions who named species and perceived them to be traded are calculated from the number who recognized each species. Numbers on the bars denote the number of interviewees who gave each response. Species are ordered by decreasing proportion of interviewees who free-listed each species.

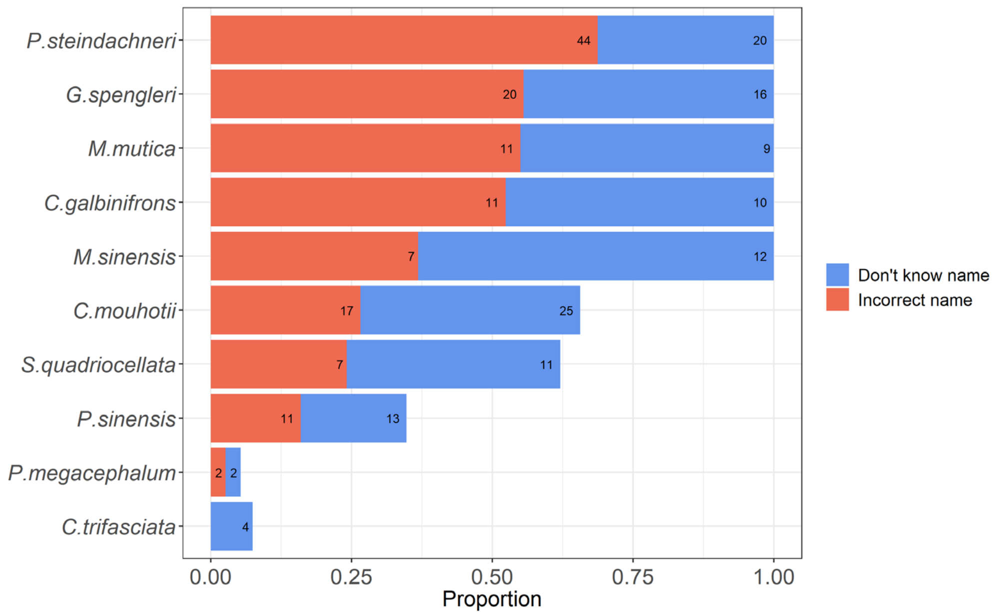

Figure 4 Proportions and numbers of interviewees who gave incorrect names or did not know the names of turtle species ($n = 175$). Proportions are calculated from the number of interviewees who recognized each species.

Rank correlations between indices of awareness and value

Market prices voluntarily reported by some interviewees reflect a wide range of perceived economic value between species (Fig. 5). The price of golden coin turtle was mentioned voluntarily by most interviewees (12), in contrast to few responses for all other species (0–5). The most expensive species based on researchers' knowledge of the market was also the species most reported to be traded (gold coin turtle, by 40 of 54 interviewees who recognized it). The cheapest species, the Chinese softshell turtle, was the second most reported to be traded (by 39 of 69 interviewees who recognized it). A higher proportion of interviewees overestimated the price of golden coin turtles (83%; 10 out of 12 people gave prices above the range provided by researchers) compared with interviewee estimates for all other species (excluding the single outlier estimate provided for Indochinese box turtle). There was a significant correlation between a species' relative salience and likelihood of being named (correlation coefficient = 0.89, $P = 0.0012$), but not between any other indices of awareness and independently obtained market prices, or between the ranks of any other attributes following Bonferroni correction (Table S3).

Predictors of knowledge about species and trade

The village location was a significant predictor for all four indices of turtle species awareness (negative binomial GLMs, $n = 151$, df = 2; free-listed, $R^2 = 0.131$, $\chi^2 = 11.317$, $P = 0.003$; recognized, $R^2 = 0.221$, $\chi^2 = 14.554$, $P = 0.001$; named, $R^2 = 0.241$, $\chi^2 = 23.864$, $P < 0.001$; reported trade, $R^2 = 0.131$, $\chi^2 = 11.317$, $P = 0.003$; see Table S4 for all test results and Fig. S1 for incidence rate ratios). Interviewees in Qingsong were more likely to recognize (estimate = 1.192, standard error = 0.346, z-value = 3.449, $P = 0.001$) and name more species (estimate = 1.418, standard error = 0.427, z-value = 3.318, $P = 0.002$), although differences between the three areas were not significant in post-hoc tests for free-listing and reported species trade (see Table S5 for Tukey post-hoc test results).

Gender was a significant predictor for the number of species recognized (negative binomial GLM, $n = 151$, $R^2 = 0.221$, $\chi^2 = 5.763$, df = 1, $P = 0.016$) and named (negative binomial GLM, $n = 151$, $R^2 = 0.241$, $\chi^2 = 8.991$, df = 1, $P = 0.003$), with men knowing more species than women (recognized, estimate = 0.345, standard error = 0.156, z-value = 2.207, $P = 0.027$; named, estimate = 0.542, standard error = 0.202, z-value = 2.690, $P = 0.007$). Older people were more likely to recognize more species (estimate = 0.013, standard error = 0.006, z-value = 2.153, $P = 0.031$). Education level, frequency of forest and county town, and distance to county town were not associated with any variation in awareness (Table S4).

Whether interviewees voluntarily provided price data for one or more turtle species was predicted by the number of species they recognized (binomial GLM, $n = 161$, $R^2 = 0.205$, $\chi^2 = 17.98$, df = 1, $P < 0.0001$) (see Table S4 for all test results and Fig. S2 for odds ratios). Interviewees who recognized more species were more likely to provide price data (estimate = 0.478, standard error = 0.186, z-value = 2.569, $P = 0.01$).

Discussion

Our investigation of patterns of local knowledge of Hainan's native turtles clarifies the relationship between awareness and

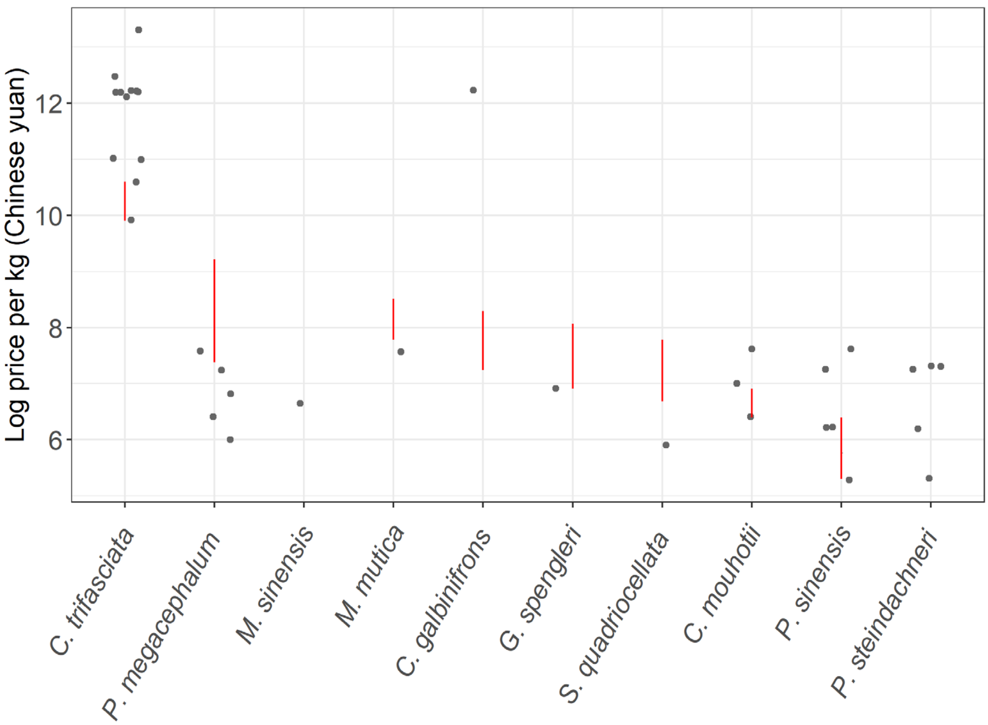

Figure 5 Market prices (means and ranges) for native Hainanese turtle species. Estimated prices voluntarily provided by interviewees are shown by dots (each dot represents a separate interviewee). Estimated recent market price ranges for wild-caught turtles are shown by lines. All prices are rounded to the nearest yuan per kg (1 GBP = c.8.8 CNY/yuan)

trade of conservation-priority species among key stakeholders at the start of a wildlife supply chain. Whereas some turtle species were much more salient and well-recognized than others, with awareness associated with demographic and local factors included in our models, we detected no relationship between relative levels of awareness and market values of different turtle species. These findings thus provide a new baseline on knowledge patterns and gaps in community perceptions of a poorly-studied conservation-priority species group, and have important wider implications for assessing the usefulness of local ecological knowledge in understanding the dynamics of wildlife trade and predicting its impact on threatened turtle faunas.

Around BNNR, local awareness varied across the 10 native turtle species, as well as across the four indices of awareness. Some species, such as big-headed turtle, golden coin turtle and Chinese softshell turtle, were considerably better known, with more people free-listing them and/or knowing their names when shown photographs. Unfortunately, no comparative multi-species regional baseline monitoring or survey data exist to determine whether variation in awareness across native turtles reflects underlying ecological variation in species abundance or rarity, or other non-ecological factors. For example, the big-headed turtle, the most frequently recognized and correctly identified species, has a distinctive appearance that likely contributes to its local familiarity. The golden coin turtle is widely known in China due to its huge popularity as a pet, food and medicine, which has led to the collapse of wild populations since the 2000s (Shi, 2006); interviewees may therefore be familiar with this species, at least by name, even if they are unlikely to have seen a wild individual (Lau & Shi, 2000; Shi, 2006), and it is noteworthy that this was the most frequently free-listed species but not the most frequently recognized or correctly identified from photographs. Species that are widely farmed for consumption, such as the Chinese softshell turtle, might also be expected to be better-known than less commercially exploited species (Gong *et al.,* 2018).

Irrespective of variation in indices of species-level awareness, all native turtle species were reported to be traded by at least some interviewees. Local awareness of the wider market is not surprising, as turtles are commonly consumed as food in China, and there is widespread farming of highly threatened turtle species that are caught from the wild by local people and sold to commercial farms (Shi *et al.,* 2007). Prices estimated by interviewees were broadly similar to price ranges provided by researchers, with interviewees aware that the golden coin turtle is substantially more valuable than other species. Interestingly, interviewees with more awareness of turtle species were more likely to report market prices, rather than prices being reported by interviewees with demographic characteristics frequently associated with greater ecological knowledge (e.g. older men; Turvey *et al.,* 2010; Kai *et al.,* 2014), suggesting that familiarity with taxa is related to knowledge of trade. This metric might therefore represent an indirect means to assess potential levels of trade in future studies.

However, the lack of correlation between awareness and relative market values of different turtles in our study indicates that local people are not necessarily familiar with the illegal trafficking of particular highly-coveted species, especially those sold on the black market. For example, although the big-headed turtle was the most frequently recognized and correctly identified species, only a relatively low proportion of interviewees thought it was traded despite its high market prices, common occurrence in pet markets in southern China, and known incidences of international trafficking (Gong *et al.,* 2017; ZSL, 2019). Due to the opaque nature of illegal wildlife trade and the recent shift of substantial trade activity to online platforms via private social media groups, specific information about the prices of particular high-value species is becoming more difficult to obtain (Esmail *et al.,* 2020). Rural communities in Hainan have previously been shown to have considerable knowledge of trade dynamics and prices of some distinctive high-value traded species, such as Chinese pangolin (Wang et al., 2021b). However, our study demonstrates that whereas local people may be knowledgeable about the ecology, behavior and distribution of native wildlife, unless they are directly involved in trading they should not be assumed to be familiar with the market.

Overall, these findings indicate that assessing local knowledge levels about at-risk turtle species does not correlate to a straightforward measure of likely levels of species-specific hunting. Some demographic predictors of increased local awareness of turtles in our models, notably age and gender, are consistent with patterns shown by previous community-based conservation studies in rural China and elsewhere (Turvey *et al.,* 2018; Qian *et al.,* 2022), and could potentially be controlled for if future survey work aimed to collect further interview data to guide turtle conservation planning (e.g. preferential targeting of older male respondents to maximize collection of relevant data, through approaches such as snowball sampling; cf. Newing, 2011). However, other differences in turtle-related knowledge detected across interviewees from different village areas around BNNR highlight more complex underlying heterogeneity in local perceptions. Potentially greater spatial variation in indices of knowledge might therefore be expected across wider landscapes, presenting additional challenges for using local knowledge to understand the extent and magnitude of trade at a larger scale.

Our findings pose limitations on the usefulness of local ecological knowledge, a potentially important data source for conservation, to understand the distribution and threat status of turtles in Hainan. Other than golden coin turtle and big-headed turtle, there is little evidence that most turtle species were reliably differentiated by people living close to forest habitats on Hainan; patterns of local ecological knowledge in this system are highly variable, and differ according to species and to attributes of individual people (cf. Mikołajczak *et al.,* 2021). Confusion may also arise between widely farmed or consumed species and related rare wild species (e.g. Chinese softshell turtle and wattle-necked softshell turtle).

These results have important conservation implications. Turtle harvesting is known to be ongoing in Hainan, including within protected areas (Gong *et al.,* 2017), and there is low local conservation concern about turtles (Gong *et al.,* 2006). Limited differentiation between species could therefore exacerbate the turtle crisis if threatened species are traded even if they are not deliberately targeted. Indeed, the relationship between local knowledge and local harvesting for trade may be complex, with impacts on species potentially influenced by specific well-connected individuals who are familiar with markets, irrespective of wider knowledge levels across communities (‘t Sas-Rolfes *et al.,* 2019). Enforcement of species-specific legislation and illegal trade restrictions might also be hindered by the limited accuracy of local species identification, with associated potential for intentional or accidental misidentification by stakeholders in wildlife trade chains (Giovos *et al.,* 2020). Limited discrimination between species further indicates that promotion of captive-bred individuals as a potentially sustainable alternative to use of wild animals should be approached with caution (Shi *et al.,* 2007; Xiao *et al*., 2021a).

This study responded to the need to evaluate the local ecological knowledge held by rural communities involved in wildlife trade (Roe & Booker, 2019), and has contributed new understanding of both patterns and potential conservation applications of local awareness of traded species. Our findings show that high-value turtles are not necessarily well-known or readily recognized at the species level by the people who potentially catch and trade them, and thus provide a first baseline of evidence for designing community-based conservation outreach programs to reduce the impacts of turtle harvesting. Such programs could provide benefits for regional turtle conservation by increasing local knowledge, awareness and pride in threatened species if tailored to the study system. Conservation outreach is needed not only within local communities to reduce turtle harvest from the wild; awareness of the perilous status of most Hainanese turtles should also be greatly increased among consumers and government and law enforcement agencies, and among conservation organizations and funders to increase attention to this major conservation problem. Additionally, more sophisticated and evidence-based strategies should be applied to consumer behavior change and enforcement, such as more consistent penalties for traders, since raising awareness alone is often not enough to change motivations and behaviors in wildlife trade and consumption (Toomey, 2023). We also recommend that future studies should adopt interdisciplinary approaches to account for cultural and linguistic influences that may be unique to a particular system; for example, interviews could be conducted in multiple languages to include ethnic minority languages and/or local dialects when possible, thereby maximizing knowledge capture. These approaches are widely transferrable to other study contexts and would greatly aid efforts to conserve species threatened by trade.

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Authors' contributions

HM, SKP and STT conceived the ideas and designed the methodology; *HM, GT, WX, YC and ZH* collected the data; HM, SKP, STT and JB analyzed the data; HM led the writing of the paper; XF and DG provided logistical support and expertise at the field site; and HM, SKP, STT, XF, DG and JB revised and approved the final paper.

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Conflict of interest

The authors declare no conflict of interest.

Data availability statement

The datasets collected during this study are available from the corresponding author upon request. Data are not publicly available because they contain potentially sensitive information on the interviewees' location, behavior and personal opinions that may compromise their identities and safety.

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Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1. Names of ten native Hainan freshwater turtle species and their conservation status and prioritization.

Table S2. Summary of demographic characteristics (predictors of GLMS) of all interview interviewees.

Table S3. (a) Spearman's rank correlation coefficients ρ for all comparisons between the ranks of species salience, recognition, being named, being thought is traded, prices provided by interviewees, and prices provided by researchers (n = 9). (b) P-values for all comparisons.

Table S4. Negative binomial generalized linear model predictors and model outputs for four indices of local people's perceptions of native turtle species.

Table S5. Tukey post-hoc test results are shown for differences between village areas. For all four generalized linear models, village area and was a significant predictor for the number of species free-listed, recognized from photos, named, and thought to be traded.

Figure S1. Frequency distribution of the number of species interviewees recognized (left) and correctly named (right) across the entire sample (n = 175). Proportions are shown on x-axis; numbers of people are shown above each bar.

Figure S2. Incidence rate ratios of each GLM for four indices of local people's perceptions of native turtle species (n = 151 for all models): (a) free-listing more species; (b) recognizing more species from photographs; (c) naming more species; and (d) reporting more species are traded.

Figure S3. Odds ratios for indices of whether someone was able to voluntarily provide a price of at least one turtle species (n = 161).